Heat Illness
Fluids & Electrolytes in Exercising Individuals

The Sports Medicine Core Curriculum Lecture Series
Sponsored by an ACEP Section Grant
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Objectives

Differentiate types of exertional heat illness and appropriate treatment.

Determine which types of exertional heat illness need to be transported to the hospital.
PATIENT #1

18 yo FB player collapses during a pre-season non-contact practice after doing gassers.
Patient #2

21 yo biker collapses after a work-out with the strength and conditioning coach.
Patient #3

40 yo female runner crosses the marathon finish line in 3:59:30 and begins to get muscle cramping and feel a little light-headed and nauseous.
Heat Stroke

Common and can be deadly
8 HS and college deaths from heat illness in 2008
31+ deaths from heatstroke since 1995
Highest incidence in late summer
i.e. football, soccer, track and field

*National Center for Catastrophic Sport Injury Research
Heat Production - Endogenous

Muscles can generate 20+ times as much energy at work than at rest;
  Only 25% efficient - rest goes to heat release
  Core temp +1°C per 5 min; 30 min -> 105°F
Basal Metabolic Rate: 100 kcal/hr -> +2°F/hr
Intense exercise: 1000 kcal/hr, 90% by muscle
Dehydration - for each 1L deficit, temp +0.3°C
Heat dissipation impaired by clothing, ointments, etc.
Heat Gain- Exogenous

Environment- hot
- radiation (sunlight) +150 kcal/hr
- conduction (temperature)
- convection (lack of wind)
- lack of evaporation (humidity)

Clothing- dark colors absorb heat/light rays
Heat transfer

Evaporation

Sweat vaporization, predominant at temps > 68; 0.6 kcal/mL

Radiation

Energy transferred via electromagnetic radiation from high to lower energy surfaces; may cause heat GAIN at temperatures > 90 F; 65% heat loss in cool environment

Convection

Heat transferred via circulating fluid/air, i.e. wind/fan

Conduction

Heat transfers from warmer to cooler objects by direct contact, i.e. ice packs (water:air = 32:1)

*effected by temperature, humidity, breeze, cloud cover/shade, clothing, surface area, sweat volume
Heat transfer and dissipation

Body is like a thermostat
Rise in core temp

- thermodetectors in hypothalamus, spinal cord and limb muscles
- sweating, vasodilation of skin vessels, increased HR and RR
Cardiac output and plasma volume

Approx 15% of intravascular volume is shunted to working muscles

Additional 15-25% cardiac output shunted to skin

Sweating can produce losses of 1-2 L/hr
Dehydration

Sweat is hypotonic; even less so in well-conditioned and heat-acclimatized athletes

May not be thirsty until lose 2% of body weight

Dehydration + exercise (heat stress) = decreased stroke volume
Cumulative dehydration

Insidious onset
Most athletes replace only approximately 50% volume lost during exercise
Can check urine dipstick to assess
Weigh in before and after workout to determine amount of fluid loss
Hubbard’s “energy depletion model”

Elevated skeletal muscle temperature increases metabolic rate

Elevated temperature causes increased cell membrane permeability and leakage of sodium, potassium ions $\rightarrow$ compensatory cell membrane ion pumping and energy drain

Build-up of lactic acid, fatigue and cell swelling

Muscles fail to relax and get weakness/tightness
Acclimatization

Physiologic changes - response to heat exposure

- Earlier vasodilation and sweating
- Increased blood plasma volume
- Increased sweat rate and decreased sodium losses
  - Unacclimated 1.5L/h, Na+ 100mEq/L
  - Acclimated 2.5 L/h, Na+ 75mEq/L

Core temperature lower at given work load/heat stress

After a week of daily exercise in the heat,

basal body temperature -0.9 °F (0.5 °C) (Buono et al 1998)
Acclimatization

7-10 d heat exposure
75% effect first 4 days

100 minutes daily (Lind & Bass, 1963)

Effect persists 1-4 weeks (Pichan et al., 1985)

Every third day for 30 days same as exercising every day for 10 days (Fein et al 1975)

30 min per day at 75% VO2max as effective as 60 min at 50% (Houmard et al., 1990)
Acclimatization- NCAA

Division I: Football Training Camp Rules

first five days one practice/day
one practice/day during school + 1 week prior to game
practices limited to 3 hours
contact:
  • helmets only day 1,2
  • helmets + shoulder pads day 3,4
no back to back two-a-day practices
3 hours recovery between practices
Heat shock proteins

Respond to stress and synthesize proteins to protect against normally lethal conditions
Refold denatured proteins into their normal configuration and stabilize them

Threshold temperature for HSP induction not constant
Type of cell, duration, rate of rise, normal environment
Different proteins for short vs long-term acclimation
Risk factors for Heat Stroke

Hot, humid environments (previous day is best predictor)
Dehydration
Barriers to heat evaporation-equipment
Illness
History of heat illness
Increased BMI
Poor physical condition

Lack of acclimation
Dark clothing
Over zealous Medications/drugs
  Caffeine, theophylline
Electrolyte imbalance
Predisposing Illnesses
  Cystic fibrosis
  Sickle cell trait
What is the spectrum of heat illness?

Heat edema
Heat rash
Heat cramps
Heat syncope
Heat exhaustion
Heat stroke
Hyponatremia
Heat Edema

Heat acclimation ->
Peripheral vasodilation ->
Increased aldosterone ->
Sodium and water retention
Dependent edema

Rx: supportive care

No diuretics
Heat Rash = Prickly Heat = Miliaria Rubra

Erythematous papules
Clothing covered areas
Keratin plugs
Itching/burning
*Impairs heat dissipation

Rx: cleanse, cool, dry skin
Sweat gland recovery 7-10 d
Heat cramps

Acute, painful muscular tightening and spasming

Lower limbs most commonly affected

Dehydration, increased lactic acid, electrolyte depletion, neuromuscular fatigue, and failure of body’s thermoregulatory mechanism
Heat cramps- Treatment

Rest

Massage/stretch/Ice

Replete electrolytes: sodium, potassium, magnesium, and calcium

Salt solution- 1 tsp table salt/1 qt water

Rehydration- po versus IV fluids

*If prolonged cramping consider sickle trait or rhabdomyolysis
Heat syncope

Transient hypovolemic syncopal episode due to decreased blood volume returning to heart
* worse with unacclimated, CV disease, diuretics
At END of race/competition
Maximal vasodilation leads to pooling of blood in lower limbs when exercise stops
Rx-Lie down, elevate legs, rest in cool place, drink cold fluids
Heat Exhaustion

Sodium depletion
Rehydration with water

*Hyponatremia*
Weakness/Fatigue
Headache
Nausea/Vomiting
Muscle cramps

*Water depletion*
Low fluid intake
Large sweat loss

*Hypernatremia*
Weakness/Fatigue
Mild Confusion
Thirst
# Heat Exhaustion

**Mild**
- profuse sweating
- headache
- dizziness
- nausea/vomiting
- weakness/fatigue
- visual changes
- cutaneous flushing

**Treatment**
- remove clothing
- cool down
- oral rehydration
- rectal temperature
# Heat Exhaustion

## Severe
- Temperature $< 104^\circ F (40.0^\circ C)$
- Tachycardia
- Hyperventilation
- Hypotension
- Decreased urine output
- Decreased sweating

## Treatment
- Remove clothing
- Cool down
- Oral rehydration
- IV rehydration
- Rectal temperature
- +/- Transport to ER
Heat Stroke

Classic
- exogenous heat
- impaired dissipation
- dry skin
- peripheral vasoconstriction

Exertional
- endogenous heat
- sweating
- peripheral vasodilation
Heat Stroke

Criteria
- Temp >104°F, rectal
- CNS changes- confusion, behavioral changes, irritability, apathy, irrational, ataxia, delirium,
- seizure (25-50%), LOC, coma

Treatment
- remove clothing
- **rapid cool down:** fanning, ice packs, immersion
- avoid shivering
- iv rehydration
- rectal temperature
- transport to ER
- seizure/muscle cramping control
  - benzodiazepines
- core cooling
Heat Stroke

Above 42°C:

Uncoupled oxidative phosphorylation
Proteins denature- enzymes impaired
Lipid liquefaction- cell membrane integrity
Organ Failure
Heat Stroke-Complications

heart failure, arrhythmias
rhabdomyolysis, renal failure
hepatic failure
brain
pulmonary-ARDS
hematologic-DIC
electrolytes- hyperkalemia (2` to cell death)
lactic acidosis
Heat Stroke

Treatment Caveats

Avoid excessive hydration which can cause pulmonary and cerebral edema

Alkaline IVF when treating rhabdomyolysis

Administer benzodiazepines to stop shivering

Monitor hydration

- Swan Ganz/Foley-urine output

Do not give Ringer’s lactate (due to K+):

\[5.96\text{g NaCl}, 3.1\text{g sodium lactate (NaC}_3\text{H}_5\text{O}_3\text{), 0.3g KCl and 0.2g CaCl}_2\]
Heat Stroke- Cooling

Cool first, transport second

Avoid overcooling- stop active cooling at 102°F (38.9°C)

Avoid shivering
Cooling

Non-Invasive
Cool environment
Misting + Fans: -0.2°C/min
Ice packs over major vessels
Cool p.o. fluids
Immersion: up to -2.5°C/min
Cooling

Invasive
Foley irrigation
Gastric lavage: -0.15°C/min
Rectal lavage
DPL
Dialysis
Heat Stroke - Cooling

Ice-water immersion cools 2X evaporation
Cold water cools as fast as ice water

Falmouth Road Race (Roberts, 1998)

10-15 runners/yr

rectal temperatures 106-110 °F

observed 20-60 minutes after cooling
walked away, no hospitalizations
Heat Stroke- Prognosis

Every minute counts
Morbidity correlates with duration and magnitude of hyperthermia (area under the curve)
With fast cooling, survival rate approaches 100% (Kark et al., 1996)
Febrile @2 hours exposure- 70% mortality
Poor outcome if:
   T>42.2°C, SGOT >1000, coma>4 h, DIC
Overall mortality 15%
Medications & Heat Illness

Uncouple oxidative phosphorylation
salicylates

Blunted cardiac response
calcium channel/beta blockers

Increase heat production/muscle activity
stimulants, thyroid hormone, neuroleptics,
drugs of abuse- cocaine, PCP, LSD, ephedra
Medications & Heat Illness

Decrease heat loss
inhibited sweat response
  • anticholinergics/ antihistamines/tricyclic antidepressants
vasoconstrictors
  • cocaine, (pseudo)ephedrine
hypovolemia
  • diuretics/caffeine/alcohol
Prevention of Exertional Heat Illness

Progressive intensity and duration of training over 10-14 days prior to event under same heat conditions

Important to drink and cool body down between practices on same day/successive days due to cumulative losses

Match fluid losses with sodium-containing fluids
   Urine should be light yellow
   < 2% body weight change- no practice unless within 2%
   weekly baseline body weight
Prevention

Sleep 6-8 hrs/night in cool environment

Well-balanced diet

NATA statement, “If the WBGT is greater than 28 C (82F, or ‘‘very high’’) an athletic event should be delayed, rescheduled, or moved into an air-conditioned space, if possible.”
Wet Bulb Globe Temperature Index

WBGT = 0.1DBT + 0.7WBT + 0.2BGT

Dry Bulb Temperature- mercury thermometer
Wet Bulb Temperature (humidity)
Black Globe Temperature (solar radiant heat)
<table>
<thead>
<tr>
<th>American College of Sports Medicine Risk Category</th>
<th>Wet Bulb Globe Temp</th>
<th>National Weather Service Heat Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dangerous Zone</td>
<td>&gt;90°F</td>
<td>&gt;115°F</td>
</tr>
<tr>
<td>Very High Risk Zone</td>
<td>82 - 90°F</td>
<td>98 - 115°F</td>
</tr>
<tr>
<td>High Risk Zone</td>
<td>73 - 82°F</td>
<td>80 - 98°F</td>
</tr>
<tr>
<td>Moderate Risk Zone</td>
<td>65 - 73°F</td>
<td>65 - 80°F</td>
</tr>
<tr>
<td>Low Risk Zone</td>
<td>&lt; 65°F</td>
<td>&lt; 65°F</td>
</tr>
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</table>
Exertional Heat Stroke during a Cool Weather Marathon


3X yo M well trained, marathon time 3:15
Collapsed near finish line, agitated, diaphoretic
Start time: Temp 43`F, humidity 99%
End time: Temp 49`F, humidity 62%
27 min later rectal temp in ER= 105.3`F
Intubated, echo showed stunned myocardium
Fluid Requirements

Sedentary adult, temperate climate: 2 L/day
Sedentary adult, hot climate: 6 L/day
Athlete, hot climate: 10-18 L/day

Sweat losses during exercise: 2-3 L/hr
one pound=450ml=15 oz
Voluntary Intake Not Enough

Thirst response @ plasma osmolality +2%
Runners drink < 500 mL/h (Noakes et al 1991/1993)
Sweat rates average 1,500+ mL/h
Marathoners dehydrated @ >1,000 mL/h
Dehydration & Exercise Capacity

2.5% water loss induced prior to exercise:
30% reduction in power output (Nielsen et al 1982)

2% body weight loss dehydration prior to 1500 meter race:
3.7% slower = 6 seconds at world-class pace (Armstrong et al 1985)
Complete v Partial Volume Replacement

50 min exercise at 80% VO₂max followed by brief, high power cycling test

1300ml v 200ml replacement during first 35 min

- Heart rate lower 4bpm
- Core temperature -0.33°C
- 6% faster during last leg

70 g of carbohydrate

- 6% improved performance
Salt Supplementation

Average American diet ~10-20g
Sodium loss with exercise ~10L=29g

0.1% oral salt solution:
   2 ten grain tablets or 1/4 t in one quart

Salt tablets
   Generally not advised
   Can be useful in hot, humid climates
   Need free water access!
Water Absorption Rates

Volume: ~20ml/min; 1200 ml/hr

Carbohydrate:

>8% slows absorption

7% solution absorbed 30% faster than water
Fluid replacement

Modify drinking behavior by:
  Education
  Availability
  Palatability

Consume 500-600 mL fluid 2-3 hours prior to activity, then 200-300 mL 10-20 min prior to activity
200-300 mL every 10-20 min during exercise
Fluid replacement

Non-competitive athletes: replace at ~ 500 mL/hour
Cold water and well-balanced diet

Intense exercise for > 1 hour:
Ingest beverages containing 4-8% carbohydrates (14g/8 oz serving) and 0.5-0.7g/L Na+
Stimulate thirst centers and supplement Na+ losses

Consume ~ 20 oz fluid for every pound lost
Before, during and after meal
Locker Room Guidelines

Body weight must be within 4% baseline
prior to leaving area

Body weight must be within 1-2% baseline
prior to next practice
# Fluid Comparisons

<table>
<thead>
<tr>
<th>Solution</th>
<th>Sodium mEq/L</th>
<th>Potassium mEq/L</th>
<th>Glucose Gm/dL</th>
<th>mOsm/L</th>
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<tbody>
<tr>
<td>WHO</td>
<td>90</td>
<td>20</td>
<td>2.0</td>
<td>310</td>
</tr>
<tr>
<td>Gatorade</td>
<td>20</td>
<td>3</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>Gatorade + Gatorlytes</td>
<td>80</td>
<td></td>
<td>2.1</td>
<td></td>
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<tr>
<td>Normal saline</td>
<td>154</td>
<td>0</td>
<td>0</td>
<td>300</td>
</tr>
<tr>
<td>Table salt 1 tsp</td>
<td>125</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
Hyponatremia

AKA: “Water intoxication”
Ultra-endurance, marathon runners
Incidence up to 30% (most clinically insignificant between 125-135)
Etiology not entirely clear
  Excessive hypotonic fluid consumption
  Excessive sweat loss
  Normal levels of vasopressin and aldosterone
Slower runners and females at greater risk
Hyponatremia

Prolonged exercise prevents complete suppression of ADH
Even small amounts of ADH reduce renal excretion of water
Athlete retains ingested fluids
Na+ loss in sweat is a minimal factor in reducing serum sodium concentration
Signs and symptoms of (EAH)

Many similar to dehydration/heat illness
Early signs and symptoms:
  - Bloating
  - “puffiness”
  - Nausea/vomiting
  - Headache
More serious signs and symptoms:
  - Altered mental status due to brain swelling
    - Confusion/disorientation
    - Agitation
  - Seizures
  - Respiratory distress (pulmonary edema)
  - Obtundation
Hyponatremia


Prospective study 488 runners
13% with sodium levels < 135 meq/L
3 runners with sodium levels < 120 meq/L
Associated with weight gain during race, race time, consumption of > 3L of fluid, or consumption of fluids every mile
Not associated with type of fluid consumed
Hyponatremia


- Weight gain 2-2.9kg, 10% had Na < 130meq/L
- Weight gain >3kg, 30% had Na < 130meq/L
- Race time < 3:30, 8/195 finishers were hyponatremic (4%)
- Race time > 4:00, 32/140 finishers were hyponatremic (22%)

Longer time to consume more fluids?
Hyponatremia

2002 Christchurch Marathon study

155 runners

No cases of hyponatremia

Water stations every 5km, compared with every 1.6km in Boston and most North American marathons

Use of NSAID in 24 hours prior to race associated with significantly elevated creatinine levels
Sodium losses in sweat

Wide range of sodium concentration 20–110 mmol/L

Sodium losses not shown to be a primary cause of Exercise Associated Hyponatremia.

No difference in sodium losses between athletes who develop EAH and those who don’t.
Prevention of Hyponatremia

Do not drink > 500-1000cc/hr

Increase distance between drinking stations

Hypotonic sodium/carbohydrate solutions instead of water may help
Are NSAIDS a Risk Factor for Development of Hyponatremia?
NSAIDs and Hyponatremia

Runners using any type of NSAID (including COX2) more likely to become hyponatremic after 60km mountain run.

Athletes using NSAIDs had lower sodium and higher creatinine levels after New Zealand Ironman triathlon.

330 participants
30% NSAID use
1.8% hyponatremic → Statistical significance
NSAIDs as a risk factor?

Similar incidence in hyponatremia b/w +NSAID and –NSAID use
Almond et al. Boston Marathon Study

NSAID use associated with elevated creatinine levels.


155/296 participants
No incidence of hyponatremia
Does Creatine Increase Risk of Heat Illness?
Creatine

95% of body’s creatine stored in muscle cells

Buffer

Brief, intense bouts of exercise rely heavily on this system

> 300 studies: “creatine loading”

Increase levels by 25%

Up to 5 days before a competition
Does creatine increase risk of heat illness?

Theory: increases intracellular water

Greenwood et al 2003: NCAA DI athletes over 3 years. No significant difference b/w creatine and no creatine users on heat illness/muscle injuries

Rawson and colleagues 2001: Eccentric muscle contractions and measured levels of markers of muscle damage. Found no difference in creatine supplementation vs placebo
Does creatine increase risk of heat illness?

*Volvek at al 2001*: 20 cyclists in hot, humid environment and cycled 30 min at 60-70% peak VO2 max. Placebo vs creatine groups showed no incidence of heat illness

*Kreider and colleagues 2003*: 98 college FB players over 21 months and looked at urine and serum markers of muscle damage and found no difference on creatine vs placebo or length of creatine supplement use
If we suspect heat illness, do we really need to take a rectal temperature?
YES!

*Important to measure CORE temperature
*Oral, axillary, tympanic are inaccurate in the exercising athlete
IV versus Oral Rehydration

Conscious, cognizant athlete without nausea and vomiting can orally rehydrate
IV vs Oral Rehydration?

Rate of Perceived Exertion:
- CONTROL > ORAL & IV at 5 and 15 min
- IV significantly higher than oral at 15 min

Thirst Ratings:
- Lower (p<0.05) during ORAL than CONTROL and IV at min 0, 5, and 15.

Thermal sensation:
- CONTROL > ORAL & IV at 5 and 15 min
- IV > ORAL at 15 min

IV vs Oral Rehydration?


Take-home points

Exertional Heat Illness can be deadly
Keep athletes hydrated, but not overly hydrated
Any persistent or profound change in mental status = call 911

Education
Acclimation can improve adaptations to heat stress